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(54) Title: DRAG RECOVERY SCHEME USING BOUNDARY LAYER INGESTION

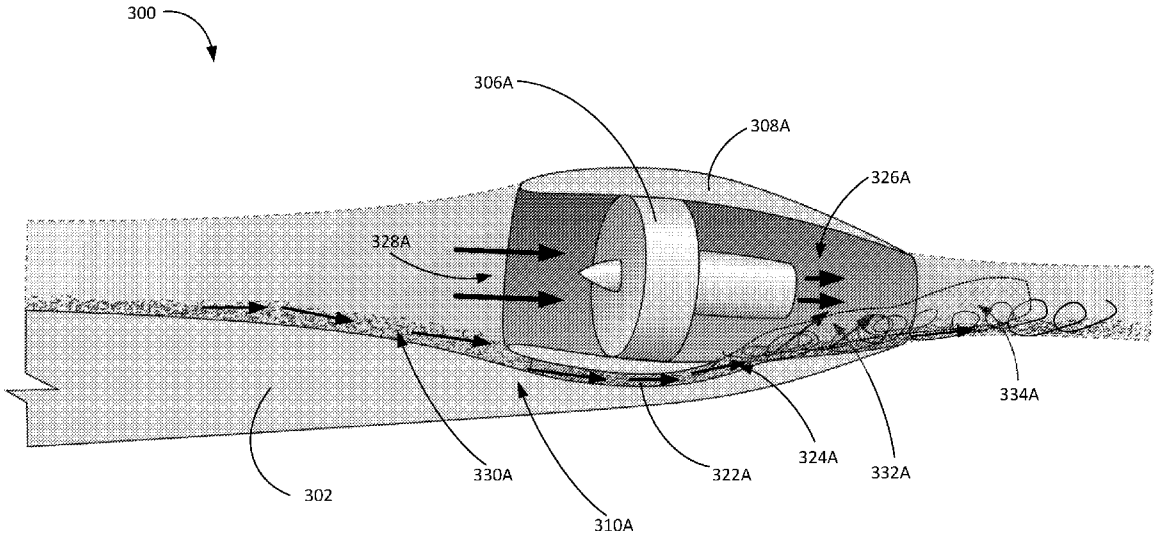

FIG. 3

(57) Abstract: Technologies are described herein for a drag recovery scheme using a boundary layer bypass duct system. In some examples, boundary layer air is routed around the intake of one or more of the engines and reintroduced aft of the engine fan in the nozzle duct in a mixer-ejector scheme. Mixer-ejectors mix the boundary layer flow to increase mass flow.

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[Continued on next page]

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DRAG RECOVERY SCHEME USING BOUNDARY LAYER INGESTION

CROSS REFERENCE TO RELATED APPLICATIONS

[0001] This application claims the benefit of U.S. Provisional Application No. 62/871,469 filed July 8, 2019, entitled "Drag Recovery Scheme Using Boundary Layer Ingestion," which is incorporated herein by reference in its entirety.

BACKGROUND

[0002] Conventional aircraft typically consist of a so-called "tube and wing" configuration, or, a blended-wing body ("BWB") configuration, where there is no clear delineation between the wings and the main body of the aircraft. When in flight, various layers of air flow form along the length of the fuselage. Closer to the fuselage, a boundary layer develops. The boundary layer is the part of the flow near the surface of the fuselage where friction slows down the local flow. Directly at the wall of the body, flow speed is zero and increases as the distance from the surface of the fuselage increases.

[0003] Boundary layer ingestion ("BLI") has been studied as a means to reduce overall airplane energy consumption by accelerating the slow wake to make thrust versus accelerating freestream flow at full flight velocity. Thrust is generated by a given accelerated a given mass flow by a given difference in velocity ("Δv"). The energy consumed varies with the given mass flow and the Δv squared. By incorporating slower inflow to the engine an energy improvement is realized.

[0004] Today, studies of jet engine BLI have been confined to BLI at the face of the engine exposing the fan to turbulent flow with a large speed difference with the rest of the inflow. This may make it difficult to design a fan blade that can tolerate the large inflow angle changes and tolerate the high loads and vibration it causes. Further, as the aircraft increases airspeed, the

various turbulent flows and the boundary layer become increasing complex to design for, resulting in a fan blade design that may be very efficient at one airspeed but inefficient at other airspeeds, or, a fan blade with mediocre efficiency over a wide range of airspeeds.

[0005] It is with respect to these and other considerations that the disclosure made herein is presented.

SUMMARY

[0006] Technologies are described herein for a drag recovery scheme using a boundary layer bypass duct system. In some examples, boundary layer air is routed around the intake of one or more of the engines and reintroduced aft of the engine fan in the nozzle duct in a mixer-ejector scheme. Mixer-ejectors mix the boundary layer flow to increase mass flow.

[0007] This Summary is provided to introduce a selection of technologies in a simplified form that are further described below in the Detailed Description. This Summary is not intended to identify key features or essential features of the claimed subject matter, nor is it intended that this Summary be used to limit the scope of the claimed subject matter. Furthermore, the claimed subject matter is not limited to implementations that solve any or all disadvantages noted in any part of this disclosure.

BRIEF DESCRIPTION OF THE DRAWINGS

[0008] FIG. 1 is a side-view illustration of a blended wing body ("BWB") aircraft using a boundary layer bypass duct system, according to various examples described herein.

[0009] FIG. 2 is a side-view illustration of a boundary layer bypass duct system, according to various examples described herein.

[00010] FIG. 3 is a side-view illustration of a boundary layer bypass duct system using multiple ducts, according to various examples described herein.

[00011] FIG. 4 is a side-view illustration of a boundary layer bypass duct system using an extended nacelle, according to various examples described herein.

[00012] FIG. 5 is a front-view illustration of an extended inlet for a boundary layer bypass duct system, according to various examples described herein.

DETAILED DESCRIPTION

[00013] The following detailed description is directed to technologies for a drag recovery scheme using boundary layer bypass duct system. As noted above, in some examples, a BWB aircraft can include one or more nacelles that house a jet engine. In some examples, the nacelles abut (or are installed onto) a top surface of the aircraft. In other examples, the nacelles are partially within the aircraft and partially outside of the aircraft ("partially hidden"). Partially hidden means that that the nacelles are partially below the surface of the aircraft.

[00014] When the BWB aircraft is moving through the air at some velocity through the use of the one or more jet engines ("main engines"), a boundary layer of air forms on the aircraft. All other factors being equal, the boundary layer forms along the entire length of the aircraft. The boundary layer represents slow or stagnant air along the surface of the aircraft, and thus, represents a force of drag while the aircraft is in motion.

[00015] In various types of aircraft in which the intake of the engine is in line with the movement of some layers of the boundary layer, such as a semi-buried nacelle, the engine design may be used to try to use some of that boundary layer air. As noted above, in some examples, some conventional engines use modified fan blades that are designed to pull in at least a portion of the boundary layer air and use the air in the engine. A problem with this approach is that, due to the changing turbulent nature of the boundary layer air at difference speeds, the fan blades can be designed either for optimal efficiency at a single aircraft speed or a moderate efficiency over a range of aircraft speeds. While providing some increased

efficiency at certain airspeeds, the use of the boundary layer air in the intake can actually reduce the efficiency of the engine at speeds for which the fan blades were not designed to be optimal.

[00016] In examples of the presently disclosed subject matter, instead of introducing boundary air into the intake of the engine, the engine is designed with a bypass duct system that pulls the boundary air around the engine, reintroducing the boundary air aft of the engine fan in the nozzle duct in a mixer-ejector scheme. Mixer-ejectors mix the bypassed external flow in a duct to increase mass flow and reduce the delta-V to make approximately equivalent thrust.

[00017] The slow-moving air introduced into the wake of the airframe can be an ideal source, even at high airplane flight speeds. The airframe boundary-layer (wake) is ducted to the inside of the fan nozzle behind the fan where it will preferably cause little no vibration or noise penalty. The slot that introduces this flow can be optimally several slot heights upstream of the nozzle exit to achieve full effect. In some examples, the boundary layer on the top surface of the aircraft and the bottom surface of the aircraft can be introduced into the bypass duct, increasing the benefit.

[00018] While the presently disclosed subject matter may be described with respect to what is termed as examples, embodiments, and the like, it is understood that the presently disclosed system is not limited to the disclosed embodiments.

[00019] Furthermore, it is understood that this invention is not limited to the particular methodology, materials, and modifications described and as such may, of course, vary. It is also understood that the terminology used herein is for the purpose of describing particular embodiments only, and, is not intended to limit the scope of the present invention. Unless defined otherwise, all technical and scientific terms used herein have the same meaning as commonly understood to one of ordinary skill in the art to which this invention belongs. Although any methods, devices or materials similar or equivalent to those described herein can be used in the practice or testing of the invention, the preferred methods, devices, and materials are now described.

[00020] FIG. 1 is a side-view illustration of a blended wing body ("BWB") aircraft 100, according to various examples described herein. The BWB aircraft includes a fuselage 102. The fuselage includes a port wing 104A and a starboard wing 104B. To propel the aircraft 100, the aircraft includes main engine 106A housed within nacelle 108A and main engine 106B housed within nacelle 108B. The main engines 106A and/or 106B may be various types of engines, including, but not limited to, turbojet, turboprop, turbofan, and turboshaft. As used herein, the nacelle 108A and 108B are housings, separate from the fuselage 102, that holds the main engines 106A and 106B, respectively. It should be noted that although the presently disclosed subject matter is described in terms of a two-engine BWB aircraft, aircraft 100, examples of the presently disclosed subject matter may be used with other numbers of main engines, or other equipment, and are considered to be within the scope of the presently disclosed subject matter.

[00021] The aircraft 100 further includes intake ducts 110A and 110B. The intake ducts 110A and 110B receive boundary air 112A and 112B, move the boundary air 112A and 112B around the main engines 106A and 106B and nacelles 108A and 108B, respectively, and reintroduces the boundary air 112A into an exhaust flow 114A of main engine 106A and an exhaust flow 114B of the main engine 106B. The movement of the boundary air 112A and 112B may be accomplished using a duct internal, external, or partially internal and partially external to the nacelles 108A and 108B. It should be noted that the presently disclosed subject matter does not require that the boundary air 112A or 112B comprise all boundary air flow that may exist, as some boundary air may still flow through a main engine intake.

[00022] FIG. 2 is a side-view illustration of the aircraft 100. In FIG. 2, the fuselage 102 is illustrated with the main engine 106A and nacelle 108A. As illustrated, a part of the nacelle 108A of the main engine 106A is partially below a surface plane AB of the fuselage 102, sometimes referred to as a "partially-buried" or "semi-buried" nacelle. It should be understood

that this is merely an example, as the presently disclosed subject matter may be used with fully or non-buried nacelles/engines.

[00023] Illustrated in FIG. 2 are three airflows. Airflow 212 generally represents the boundary layer air that forms on and proximate to the outer layer of the fuselage 102. Airflow 214 generally represents free air that flows outside of the airflow 212. The airflow 216 generally represents an interface between the airflow 212 and the airflow 214. It should be noted that the airflows 212, 214, and 216 are not drawn to any particular scale. Further, it should be noted that the air represented by the airflows 212, 214, and 216 do not have exact or clearly definable layers.

[00024] As illustrated, the airflow 212 (generally representing the boundary layer air) is introduced into the intake duct 110A, moved through passageway 222A, and is exhausted through an exhaust duct 224A, shown in more detail below. Although not beholden to one scientific principle, it is understood that turbulent entrainment of the airflow 212 essentially "pulls" the airflow 212 into the passageway 222A and the exhaust duct 224A. In the exhaust 226A of the main engine 106A, the faster flow of the exhaust 226A is slowed, and the slower flow of the airflow 212 is sped up in a "turbulent mixing" cone. The increasing of the velocity of the airflow 212 creates a vacuum, pulling airflow 212 into the passageway 222A. The reduction in pressure in the passageway 222A (causing the pulling of the airflow 212 into the passageway 222A) can be felt at the intake duct 110A, reducing the pressure buildup of stagnant boundary layer air, increasing thrust.

[00025] In a different manner than can be found in conventional aircraft, the beneficial effects of the partial vacuum in the passageway 222A generally increases as the speed of the aircraft 100 increases due to increased main engine 106A thrust. With higher main engine 106A thrust, the velocity of the exhaust 226A increases. Because the velocity of the airflow 212 is essentially constant, as the velocity of the exhaust 226A increases, the differential pressure created in the "turbulent mixing" cone in the exhaust 226A increases, thus increasing the

amount of the airflow 212 pulled into the exhaust 226A and the accompanying benefits. At some general location downstream of the aircraft 100, the airflow 212 and the exhaust 226A are completely mixed, with constant pressure and turbulent flow. Other types of mechanisms may be used to introduce the airflow 212, such as, but not limited to, venturi valves and the like.

[00026] FIG. 3 is a close-up, side-view illustration of a bypass duct system. In FIG. 3, the fuselage 302 of the aircraft 300 includes a main engine 306A housed within a nacelle 308A. The configuration illustrated in FIG. 3 is a semi- or partial-buried nacelle configuration. The fuselage 302 further includes an intake duct 310A located proximate to the intake side of the main engine 306A, a passageway 322A, and an exhaust duct 324A, which opens to the exhaust 326A of the main engine 306A. The intake duct 310A is located proximate to an intake 328A of the main engine 306A. The passageway 322A fluidically connects the intake duct 310A with the exhaust duct 324A to provide for an air passage from the intake duct 310A to the exhaust duct 324A.

[00027] The intake duct 310A is located proximate to the nacelle 308A and in line with or in the boundary layer air 330A proximate to the intake 328A. The boundary layer air 330A is introduced through the intake ducts 310A, moved through the passageway 322A, and is exhausted into the exhaust 326A through the exhaust duct 324A. The exhausted boundary layer air 332A mixes with the exhaust 326A in mixing region 334A. In some examples, the exhausted boundary layer air 332 is introduced into the exhaust 326A within the nacelle 308A.

[00028] FIG. 4 is a close-up, side-view illustration of a dual bypass duct system. In FIG. 4, the fuselage 402 of the aircraft 400 includes a main engine 406A housed within a nacelle 408A. The configuration illustrated in FIG. 4 is a semi- or partial-buried nacelle configuration. The fuselage 402 further includes an upper intake duct 410A, a passageway 422A, and an exhaust duct 424A, which opens to the exhaust 426A of the main engine 406A.

[00029] The upper intake duct 410A is located proximate to an intake 428A of the main engine 406A. The upper intake duct 410A is further located proximate to the nacelle 408A and in line with or in an upper boundary layer air 430A proximate to the intake 428A. The upper boundary layer air 430A is introduced through the upper intake duct 410A, moved through the passageway 422A, and is exhausted into the exhaust 426A through the exhaust duct 424A. The exhausted upper boundary layer air 432A mixes with the exhaust 426A in mixing region 434A. In some examples, the exhausted boundary layer air 432A is introduced into the exhaust 426A within the nacelle 408A.

[00030] The fuselage 402 further includes a secondary intake duct 436A. The secondary intake duct 436A receives secondary boundary layer air 438B located proximate to a second layer of the fuselage 402. In the example illustrated in FIG. 4, the secondary intake duct 436A is located proximate to the lower surface of the fuselage 402. The secondary boundary layer air 438A is introduced through the secondary intake duct 436A, moved through a passageway 440A, and is exhausted into the exhaust 426A through the exhaust duct 424A. The exhausted secondary boundary layer air 442A mixes with the exhaust 426A in mixing region 434A. In some examples, the exhausted secondary boundary layer air 442A is introduced into the exhaust 426A within the nacelle 408A.

[00031] FIG. 5 is a close-up, side-view illustration of a bypass duct system with an extended bypass intake. In FIG. 5, the fuselage 502 of the aircraft 500 includes a main engine 506A housed within a nacelle 508A. The configuration illustrated in FIG. 5 is a semi- or partial-buried nacelle configuration. The fuselage 502 further includes an upper intake duct 510A, a passageway 522A, and an exhaust duct 524A.

[00032] In FIG. 5, the upper intake duct 510A is located a distance XY from an intake 528A of the main engine 506A using an intake extender 530A. The intake extender 530A increases the distance from the intake 528A of the main engine 506A and the intake of the upper intake duct 510A. Locating the upper intake duct 510A from the intake 528A of the main

engine 506A can provide various benefits. For example, the partial vacuum created by the mixing in the exhaust of the engine (described above) can be felt further closer to the bow (or front) of the aircraft 500, potentially reducing the drag effect of the boundary air.

[00033] Based on the foregoing, it should be appreciated that technologies for a drag recovery scheme using boundary layer bypass duct system have been disclosed herein. It is to be understood that the invention defined in the appended claims is not necessarily limited to the specific features or acts described herein. Rather, the specific features or acts are disclosed as example forms of implementing the claims.

[00034] The subject matter described above is provided by way of illustration only and should not be construed as limiting. Various modifications and changes can be made to the subject matter described herein without following the example configurations and applications illustrated and described, and without departing from the true spirit and scope of the present invention, aspects of which are set forth in the following claims.

CLAIMS

What is claimed is:

1. A blended wing body aircraft, comprising:

a fuselage comprising a port wing and a starboard wing in a blended body configuration;

at least one engine housed within a nacelle;

at least one intake duct in line with or in a boundary layer of a top surface of the aircraft, the at least one intake duct located proximate to an intake of the at least one engine;

at least one exhaust duct located proximate to an exhaust of the main engine; and

a passageway fluidically connecting the at least one intake duct with the at least one exhaust duct to provide for a passageway of boundary layer air from the at least one intake duct to the at least one exhaust duct, and

wherein the boundary layer air moves into the at least one intake duct, through the passageway, and exhausts out the at least one exhaust duct.

2. The aircraft of claim 1, wherein the at least one exhaust duct is further configured to exhaust the boundary layer air exiting the at least one exhaust duct into an exhaust of the at least one engine.

3. The aircraft of claim 2, wherein the boundary layer air exits the at least one exhaust duct into a mixing region in the exhaust of the at least one engine.

4. The aircraft of claim 3, wherein the mixing region is within the nacelle.

5. The aircraft of claim 1, wherein the nacelle is a semi-buried nacelle configuration.

6. The aircraft of claim 1, further comprising:

a second intake duct in line with or in a second boundary layer air of a bottom surface of the aircraft;

a second exhaust duct located proximate to the exhaust of the main engine; and

a passageway fluidically connecting the second intake duct with the second exhaust duct to provide for a passageway of the second boundary layer air from the second intake duct to the second exhaust duct.

7. The aircraft of claim 1, further comprising:

a second engine housed within a second nacelle;

a second intake duct in line with or in a second boundary layer air of the top surface of the aircraft, the second intake duct located proximate to an intake of the second engine;

a second exhaust duct located proximate to an exhaust of the second engine; and

a second passageway fluidically connecting the second intake duct with the second exhaust duct to provide for a passageway of the second boundary layer air from the second intake duct to the second exhaust duct, and

wherein the second boundary layer air moves into the second intake duct, through the second passageway, and exhausts out the second exhaust duct.

8. The aircraft of claim 1, further comprising an intake extender to increase a distance from the intake of the at least one engine and the intake of the at least one intake duct.

9. A method of reducing drag on an aircraft, the method comprising:

receiving boundary layer air of a top surface of a wing of the aircraft into an intake duct located proximate to an intake of an engine housed within a nacelle of the aircraft;

directing the boundary layer air through a passageway around and outside of the engine;

exhausting the boundary layer air from the passageway into an exhaust of the engine.

10. The method of claim 9, wherein the boundary layer air is exhausted into a mixing region in the exhaust of the engine.

11. The method of claim 10, wherein the mixing region is within the nacelle.

12. The method of claim 9, wherein the nacelle is a semi-buried nacelle configuration.

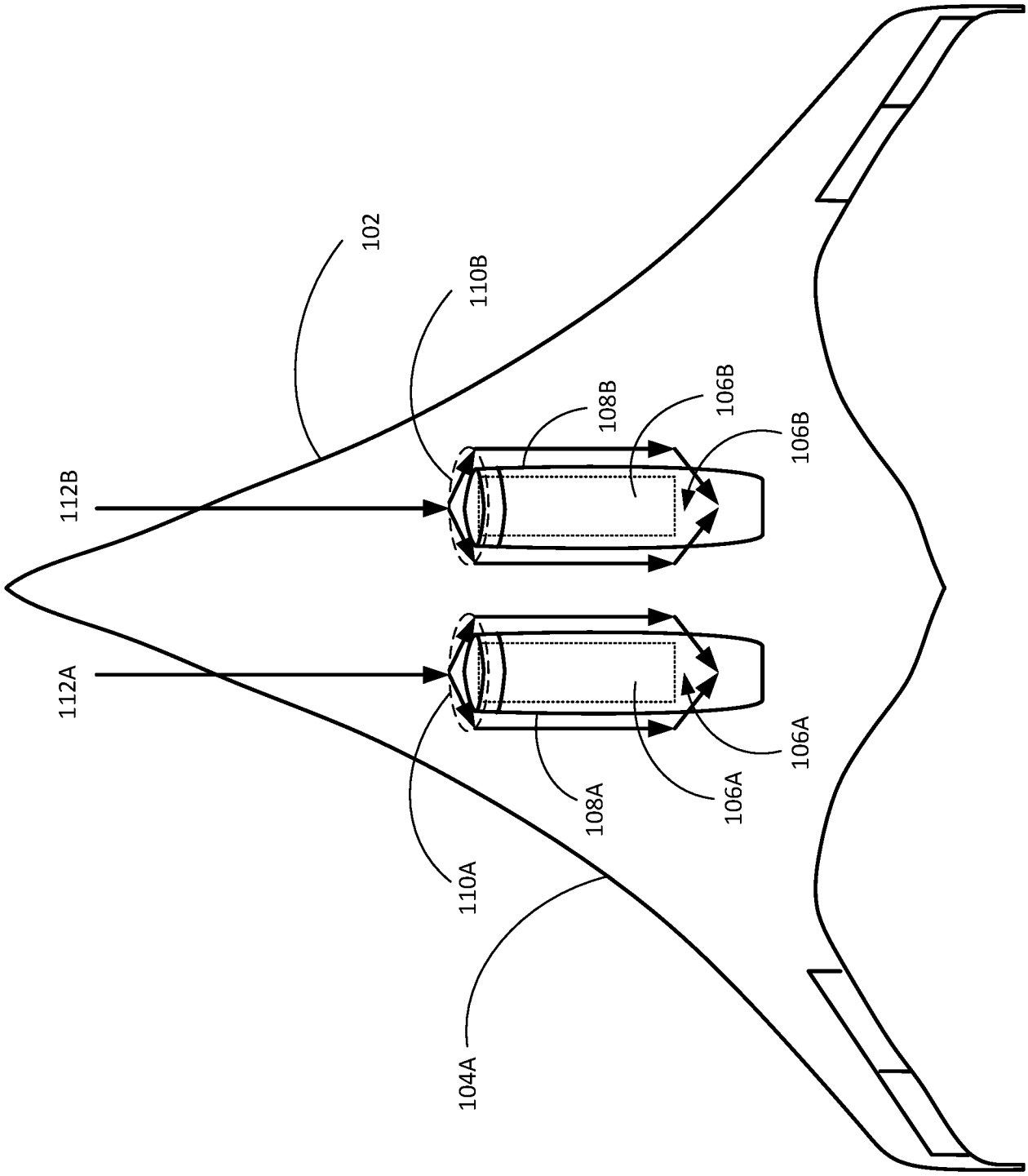

FIG. 1

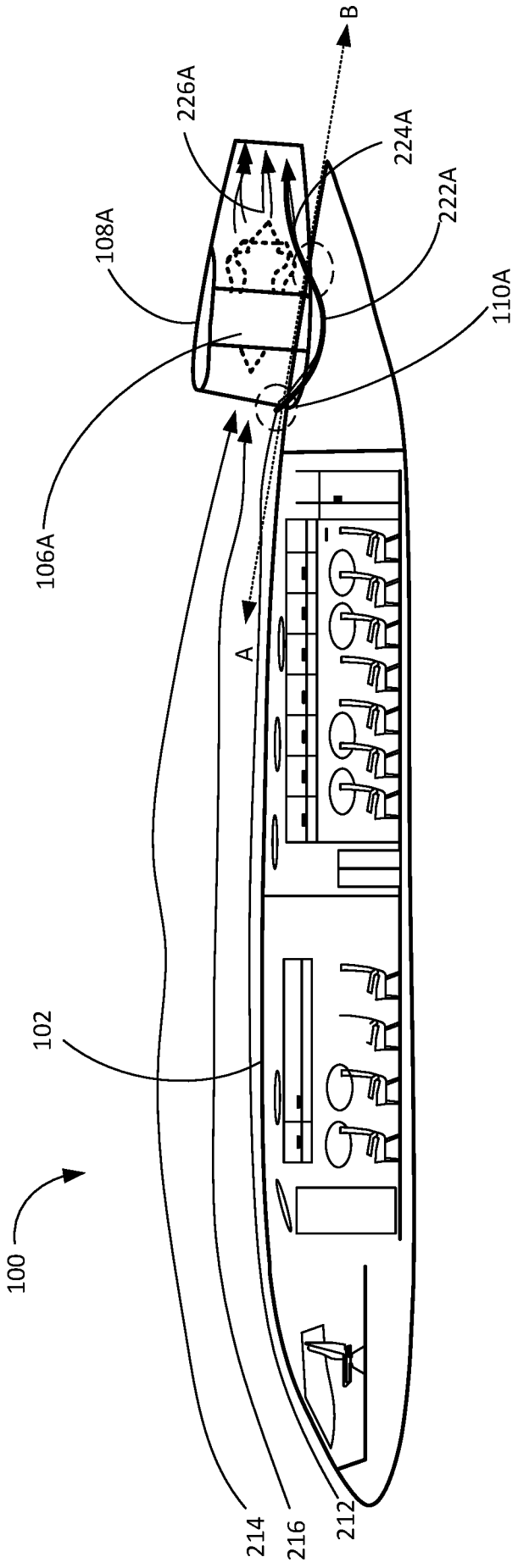

FIG. 2

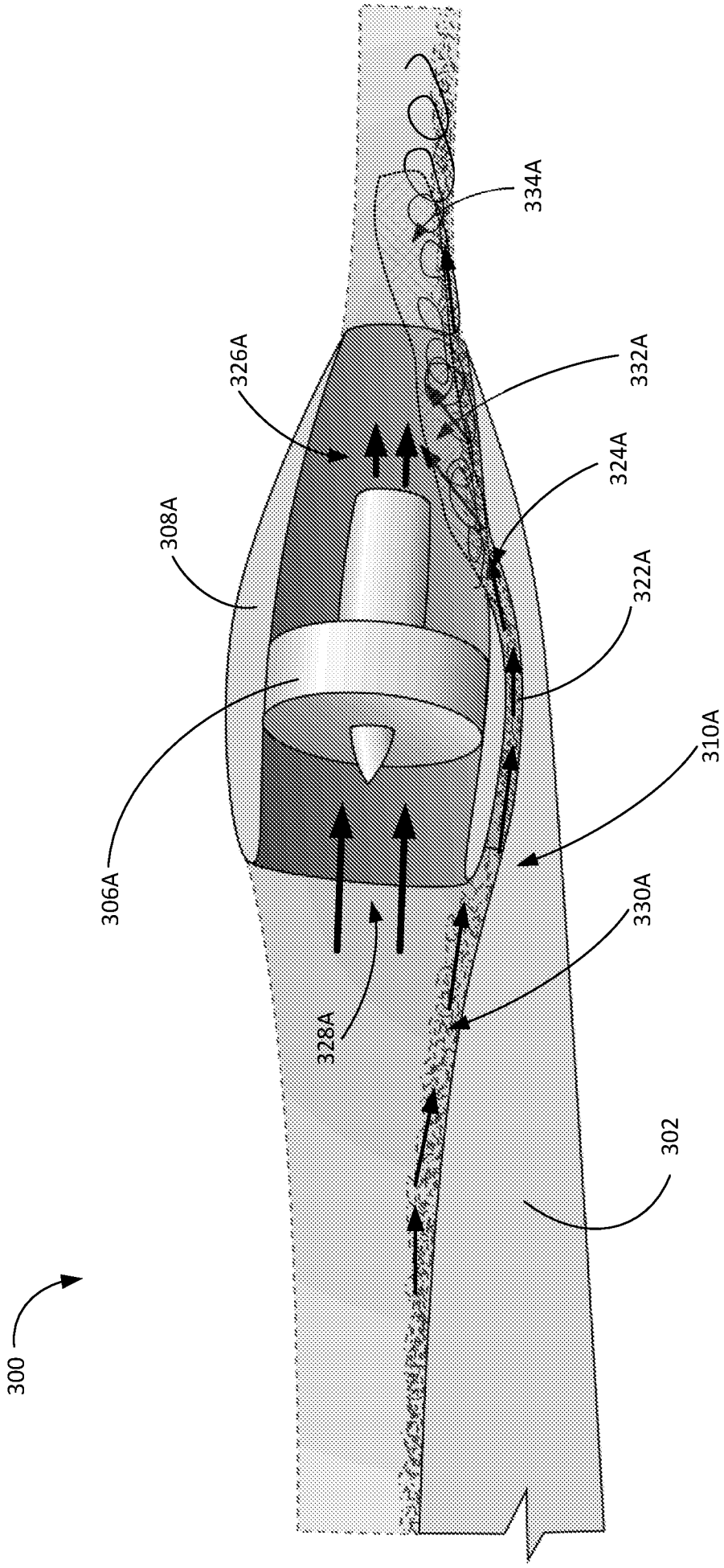

FIG. 3

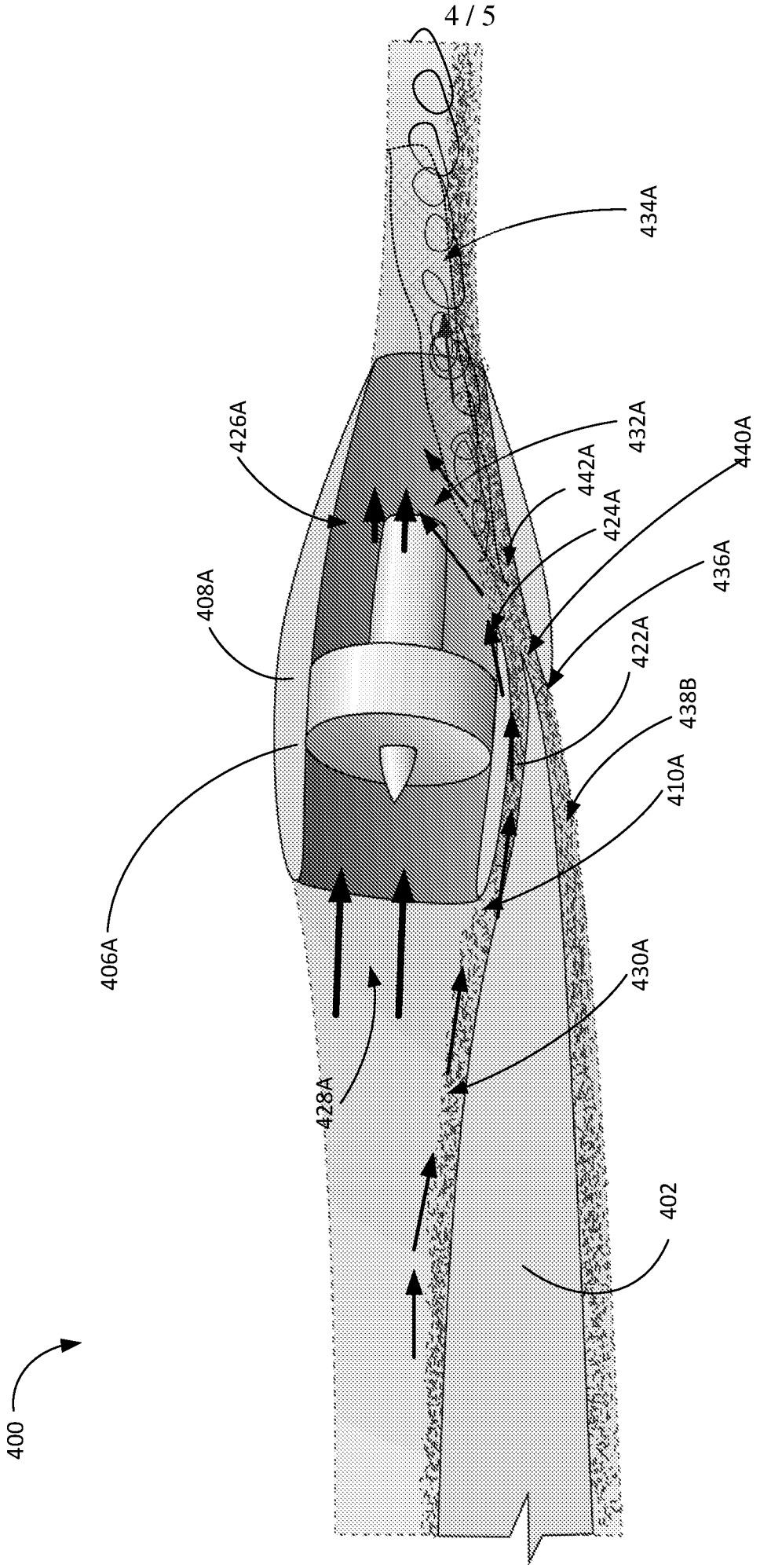
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FIG. 4

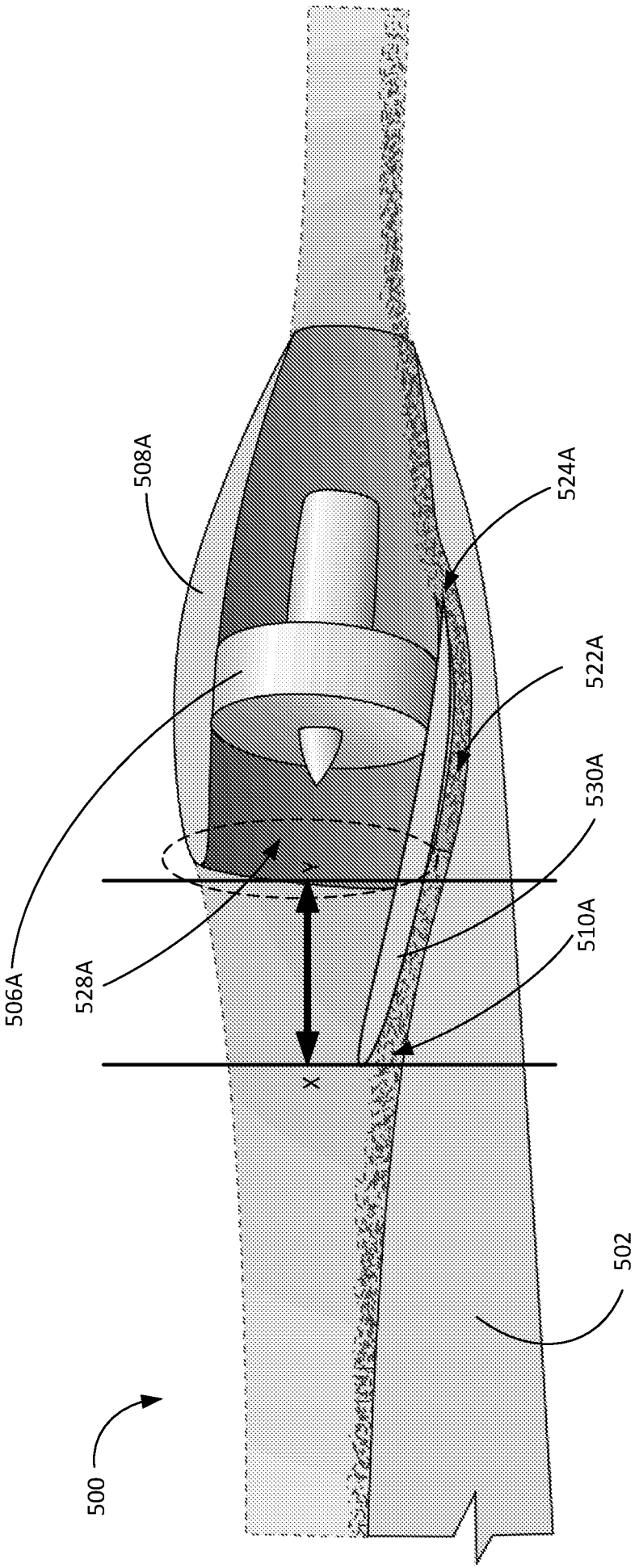

FIG. 5

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US 20/41018

A. CLASSIFICATION OF SUBJECT MATTER

IPC - F02C 7/04, B64D 33/02, B64C 21/02, B64B 1/24, B64D 27/00, B64D 29/00 (2020.01)

CPC - F02C 7/04, B64C 21/02, B64C 2039/105, B64D 27/00, B64D 27/20, B64C 2201/048, B64C 2201/16, F05D 2220/323, B64D 2033/0226, F02C 7/04

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
See Search History document

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched
See Search History document

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)
See Search History document

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X --- A	WO 2008/017567 A1 (TEAM SMARTFISH GMBH) 14 February 2008 (14.02.2008), entire document, especially Figs 2, 4, 7, 9; ln 106-109, 174-176, 211-212, 319-320	1-5, 7-12 --- 6
A	US 2003/0132342 A1 (Koncsek et al.) 17 July 2003 (17.07.2003), entire document	1-12
A	US 2004/0251378 A1 (Bagnall) 16 December 2004 (16.12.2004), entire document	1-12
A	US 2005/0178884 A1 (Schafroth) 18 August 2005 (18.08.2005), entire document	1-12
A	US 2002/0134886 A1 (Seidel) 26 September 2002 (26.09.2002), entire document	1-12
A	US 2014/0283921 A1 (SNECMA) 25 September 2014 (25.09.2014), entire document	1-12

☐ Further documents are listed in the continuation of Box C. ☐ See patent family annex.

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Date of the actual completion of the international search	Date of mailing of the international search report
25 August 2020 (25.08.2020)	30 SEP 2020
Name and mailing address of the ISA/US Mail Stop PCT, Attn: ISA/US, Commissioner for Patents P.O. Box 1450, Alexandria, Virginia 22313-1450 Facsimile No. 571-273-8300	Authorized officer Lee Young Telephone No. PCT Helpdesk: 571-272-4300